REEVALUATION OF LUNAR IMPACTOR POPULATION EVOLUTION: PRELIMINARY RESULTS FROM CRATER DISTRIBUTIONS ON DIVERSE TERRAINS.

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Introduction: The Moon is the only solar system body that we have both crater size-frequency distributions (SFDs) *and* ages of known terrains. These are keystones for understanding the impact rate through time, not only for the Moon but also the Earth, which has had much of its record erased by geologic activity. Previous work has constrained the changing lunar impact rate through time [2-8]. However, these efforts are decades old. New imaging from Lunar Reconnaissance Orbiter Camera (LROC) and results from dynamical calculations of evolution of plausible impactor populations [e.g., 9-12] encourage a reevaluation of the impactor rate. Therefore, we are compiling the crater SFDs for different lunar terrains (which will later be combined with dynamical research) to understand the evolution of the impactor populations.

Analyzed Terrains: So far we have measured craters on the Birkhoff, Imbrium, and Orientale basins. Birkhoff is one of the oldest lunar basins, while Imbrium and Orientale are two of the youngest [13]. Their SFDs and ages are very important because they could mark either end of the Late Heavy Bombardment (LHB) period. For Birkhoff, the study area includes the entire basin floor (Fig 1a). For Imbrium, we measured a small area of the mare (Fig. 1b). For Orientale, three unique regions were measured (Fig. 1c). Region 1 is flat and likely impact melt. Region 2 is undulating and likely rim material. Region 3 is low, very flat, and named Mare Orientale [e.g., 13].

Crater Measurement Methods: Within each region, craters are measured manually by digitally outlining them using a Perl add-on to SAOImage DS9. A crater is considered within a region if its center is within the region. Ellipses (or circles) are fitted to two or more user-selected points along the crater rim. DS9 assigns a grid to the image and the script attaches coordinates to each crater outline, yielding the diameter (D) in pixels. All craters $D > 5$ pixels are identified; however, only craters $D > 7$ pixels are analyzed to reduce errors due to incompleteness. We convert pixel diameter to metric units using the image resolution. These data are then converted into SFDs [14].

A degradation class was assigned to each crater, ranging from 1 (fresh) to 4 (most degraded). A crater may also be identified as an "obvious secondary" ("OS") by being part of an obvious cluster or chain. Note that our term "All Classes" in this text refers to all degradation classes, excluding "OS"s.

Another element of this study is to better understand the human variation involved in indentifying and measuring craters. Variations occur in indentifying the crater rim, the definition of what constitutes a crater, etc. Each coauthor manually outlined what they identified as craters in three Orientale Basin regions (Fig. 1c). We compared the three individual results to assess the variable personal equations.

Results and Discussion: Fig. 2 shows the SFD for each region in Relative (R) plot format [14]. The relative ages indicated by the different average spatial densities agree well with previous determinations [e.g., 13]. Birkhoff Basin, which Wilhelms showed was Pre-Nectarian, is oldest, while Mare Imbrium (Eratos-

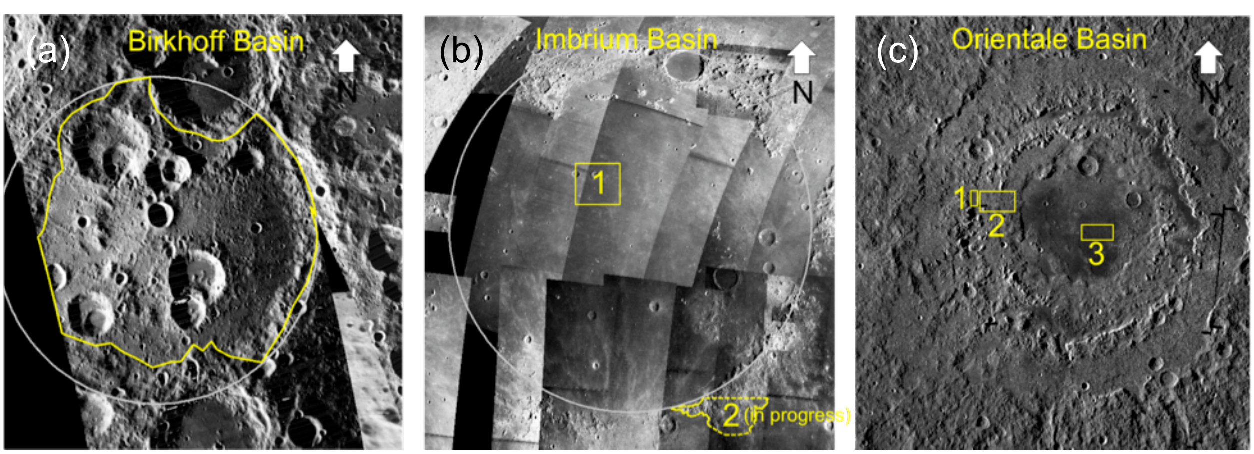

Figure 1. Regions. Basin Centers: (a) 59N, 147W; (b) 35N, 17W; (c) 19S, 95W. Resolutions: (a) 80, (b) 40, (c) 100 m/pix. Birkhoff and Imbrium mosaics of Lunar Orbiter (LO) IV and V images, Orientale mosaic generated by LROC team (http://wms.lroc.asu.edu/lroc_browse/view/orient_100m).

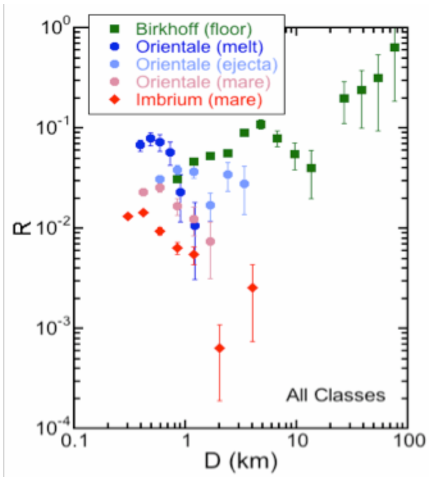

Figure 2. R-plot comparing SFDs of all regions. Errors are √*N*, where *N* is the number of craters in the bin.

thenian) is youngest. The Imbrium-aged Orientale materials fall in between. The exception is our Orientale melt pond sample (Region 1), which has a higher crater density than other terrains at D < 1 km and sharply decreasing density for D > 1 km. This may be an effect of terrain strength [15], and the resulting crater scaling and/or the crater retention capacity.

Furthermore, comparison of SFD patterns suggests a strong similarity in the impact crater SFDs of the two maria. The other SFDs in Fig. 2 are dissimilar to maria SFDs. The SFDs for Orientale ejecta and Birkhoff have higher densities of larger craters, consistent with a change in the external impactor SFD over time, in agreement with [16]. However, SFDs for D < 2 km are likely dominated by secondary craters.

Fig. 3 compares the SFDs from Fig. 2 (now also subdivided into degradation classes) with SFDs of the "obvious secondaries" ("OS") (see methods) for Mare Imbrium and Birkhoff. For Imbrium, the "OS" SFD resembles the degraded craters (classes 3+4) SFD and drops steeply for larger craters. In contrast, for Birkhoff Basin, the "OS" SFD resembles the fresh crater (classes 1+2) SFD, rising for larger craters. The SFDs for Imbrium "OS" and degraded craters resemble classic secondary SFDs enriched in small craters [3, 17]. The similarity of these two Imbrium SFDs is consistent with domination by irregularly shaped

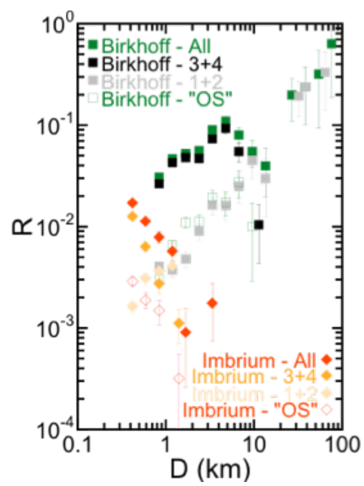

Figure 3. R-plot comparing Birkhoff and Imbrium SFDs (Fig. 2) with "obvious secondaries" ("OS").

secondaries, lacking prominent clustering. Meanwhile, the converse SFD of the Birkhoff fresh craters and "OS" suggest a different kind of secondary population, perhaps large basin secondaries, which have had minimal study [18].

Finally, we have assessed human variations in crater measurement. Fig. 4 shows the craters identified and measured by MRK (experienced crater counter) and by KMS (novice crater counter) laid onto the image of the Orientale melt unit. In general, KMS recognized more (chiefly large, degraded) craters, especially in a hillier region to center right. These results encourage further evaluation of crater recognition and class identification.

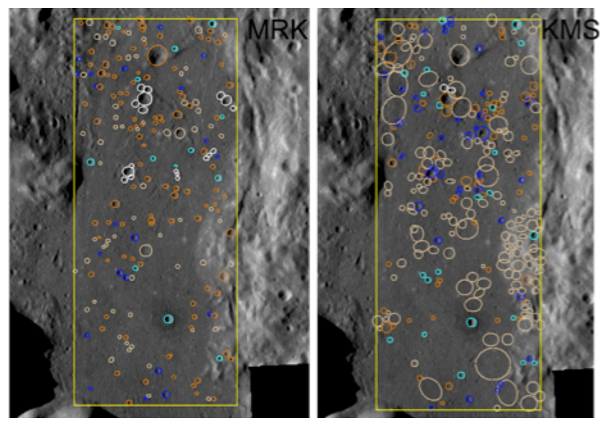

Figure 4. Comparison of crater measurements by MRK and KMS. Yellow boxes outline the region. Ellipses mark crater rims and color denotes degradation class. Cyan – class 1; blue – class 2; brown – class 3; tan – class 4; white – secondaries.

Summary: Our preliminary data are consistent with the hypothesis of [16] that the production SFD of external impactors has changed over the Moon's geologic history. They also show that crater SFDs may be considerably affected, especially at smaller sizes by unrecognized secondaries confusing identification of the primary crater production function.

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